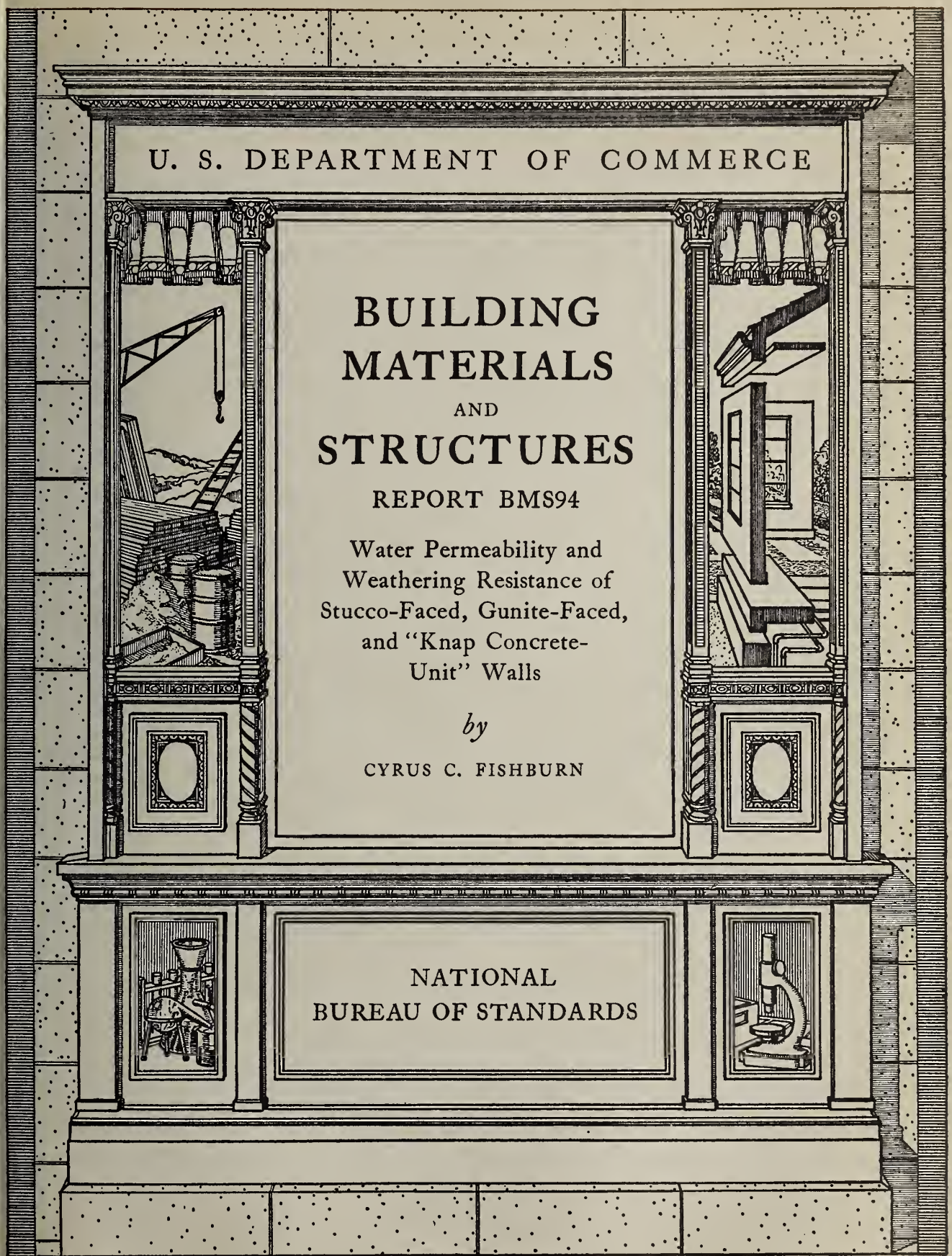
U. S. DEPARTMENT OF COMMERCE
BUILDING
MATERIALS
AND
STRUCTURES
REPORT BMS94
Water Permeability and
Weathering Resistance of
Stucco-Faced, Gunite-Faced,
and "Knap Concrete-
Unit" Walls
by
CYRUS C. FISHBURN
NATIONAL
BUREAU OF STANDARDS

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BUILDING MATERIALS *and* STRUCTURES

REPORT BMS94

Water Permeability and Weathering Resistance of Stucco-Faced, Gunite-Faced, and "Knap Concrete-Unit" Walls

by CYRUS C. FISHBURN

ISSUED DECEMBER 2, 1942

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

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Foreword

Previous Building Materials and Structures reports give the results of investigations on the permeability of walls of masonry units before and after exposure to the weather. This report deals with the resistance to water penetration of highly permeable masonry-unit backings, faced with stucco or gunite, and with the permeability of walls built of "Knap concrete-units."

LYMAN J. BRIGGS, *Director.*

Water Permeability and Weathering Resistance of Stucco-Faced, Gunite-Faced, and "Knap Concrete-Unit" Walls

by CYRUS C. FISHBURN

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ABSTRACT

The water permeabilities of small stucco- and gunite-faced walls and of walls built of "Knap concrete units" were measured before and after outdoor weathering. Six kinds of stucco facings, 2 thicknesses of gunite facings, and 7 kinds of units were represented in a group of 26 walls.

All of the stucco- and gunite-faced walls were highly resistant to water penetration. Periods of outdoor exposure at Washington, D. C., varying from 16 to 49 months, had no important effect on permeability. The resistance to penetration of walls built of "Knap concrete units" was excellent after the walls were painted.

I. INTRODUCTION

As part of an investigation on the water permeability[1] of small masonry wall specimens, 20 stucco-faced walls, 4 gunite-faced walls, and 2 walls built of "Knap concrete units" were tested before and after exposure to the weather. The effects of the following variables on the permeability of the walls are reported:

1. The kinds of backing and their moisture content.

[1] Previous publications on the water permeability of masonry walls, which also contain data obtained from tests on 8 stucco-faced walls, are as follows: Building Materials and Structures Reports BMS7, Water Permeability of Masonry Walls; BMS41, Effects of Heating and cooling on the Permeability of Masonry Walls; BMS55, Effects of Wetting and Drying on the Permeability of Masonry Walls; and BMS76, Effects of Outdoor Exposure on the Water Permeability of Masonry Walls.

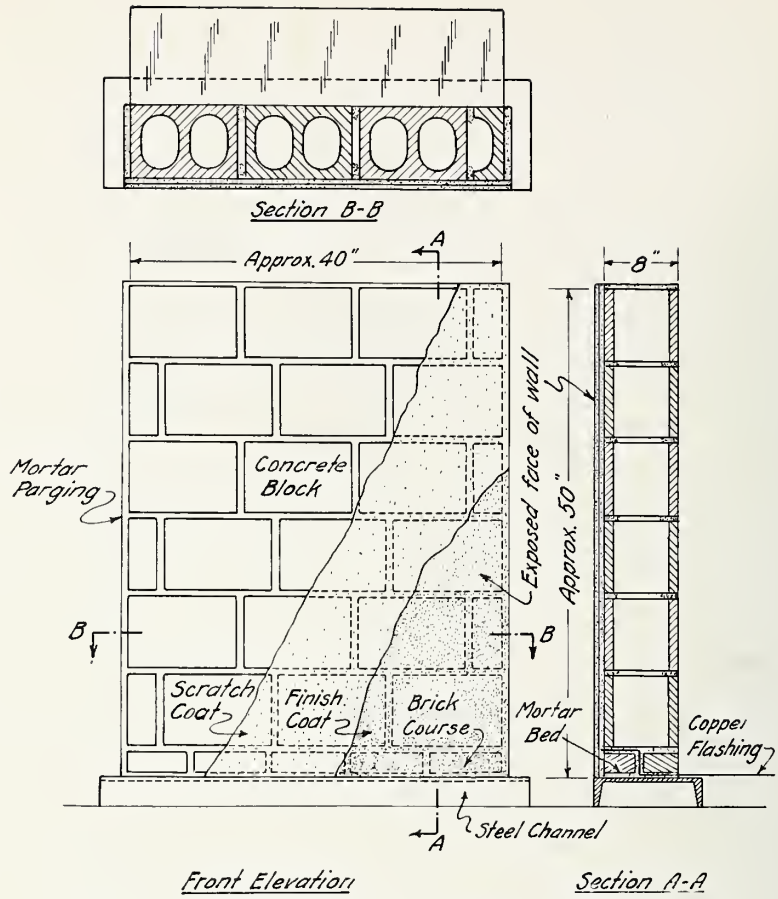

FIGURE 1.—*Typical stucco-faced wall with concrete block backing.*

2. The relative proportions of portland cement and hydrated lime in the stucco.
3. The admixture of asbestos fiber or pulverized limestone to the stucco.
4. The time interval between the application of the scratch and finish coats of stucco.
5. The curing conditions given the stucco facings.
6. The thickness and reinforcement of the gunite facings.

The effects of weathering on the permeability and structural soundness of the walls are also reported.

II. WALL SPECIMENS

The walls were about 40 in. long, 50 in. high, and 9 in. thick. They were supported on steel channels and contained copper flashings so placed that water penetrating the exposed face was diverted at the bottom of the wall to the back, where the leakage could be measured. The ends and tops of backings built of masonry units were sealed with a ⅜-in.-thick mortar parging before the facings were applied. A typical stucco-faced wall with a backing of concrete units is illustrated in figure 1.

1. SPONSORS

The stucco-faced walls were sponsored by the Government agencies that collaborated with the National Bureau of Standards in the tests. The walls were constructed at the Bureau by experienced masons.

The gunite-faced walls were sponsored by the Cement Gun Co., Allentown, Pa., and were built at the Bureau by their representatives.

The walls of "Knap concrete units" were sponsored by Knap America, Inc. The units were cast in Los Angeles, Calif., and assembled at the Bureau under the direction of the sponsors.

2. Materials

(a) *Masonry Backing-Units*

The masonry units are designated by small letters and are briefly described. The physical properties and the dimensions of the units used in the backings for the stucco-faced walls are given in a previous report [2] of this series.

Brick a were low absorptive units in a base course for hollow unit backings of walls faced with stucco (fig. 1).

Brick c were dry-press units with a high rate of absorption and were used in the backings of four stucco-faced walls. Their absorption, by weight, during a 24-hr cold immersion was about 15 percent.

Brick y were placed in the backings of two gunite-faced walls. They were second-hand (used) brick with rounded edges, and had an absorption of 18 percent during a 24-hr cold immersion.

Tile j were six-cell, 8- by 12- by 12-in. hard-burned structural clay tile made at Magnolia, Ohio, by the National Fireproofing Co. They were used in the backings of six stucco-faced walls.

Tile v were three-cell, 4- by 12- by 12-in., hard-burned, partition tile, made by the National Fireproofing Co., and were used in the backings of two gunite-faced walls.

Block m were two-cell, 8- by 12- by 8-in., stone-concrete block and were used in the backings of six stucco-faced walls.

Block n were made of cinder concrete block, and were used in the backings of four stucco-faced walls. Blocks *m* and *n* met the requirements of Federal Specification SS–C–621 for type 1, load-bearing units.

(b) *"Knap Concrete-Units"*

The two precast reinforced "Knap concrete-unit" walls were the same as those used in similar walls built for structural tests.[3] Descriptions of the units, their reinforcement, and the accessories used with them are given in BMS40.

[2] Building Materials and Structures Report BMS82, Water Permeability of Walls Built of Masonry Units. (In BMS82 the bricks are designated by capital letters.)

[3] Building Materials and Structures Report BMS40, Structural Properties of a Wall Construction of "Knap Concrete Wall Units," sponsored by Knap America, Inc.

(c) *"Bondex" Paint*

"Bondex," a cement-water paint made of about equal parts of white portland cement and hydrated lime, with a small amount of a stearate waterproofing ingredient, was applied to the exposed faces of the "Knap concrete-unit" walls. This paint, made in powder form by the Reardon Co. of St. Louis, Mo., was prepared by mixing with water.

(d) *Mortar*

The proportions of the mortars, their uses, and the kinds of cementing materials are given in table 1. Sieve analyses of the Potomac River sands are given in table 2. The mortars were proportioned by weight and mixed in a batch mixer having a capacity of about 0.6 cu. ft. The amount of water added to the mix was adjusted to the satisfaction of the mason.

Table 1.—*Proportions and kinds of cementing materials used in the mortars*

Mortar	Proportions of cement, lime hydrate, and sand[a]		Kind of cement	Kind of lime
	By volume	By weight		
2[b]	1:1:6	1:0.42:5.1	Atlas portland	Putty.[c]
3[d]	1:0.1:2	1:0.04:1.7	Medusa portland	Do.[c]
4[e]	1:0:3.5	1:0:3	Atlas portland	
5[f]	1:0:3	1:0:3.7	Brixment	

[a] Proportioning was by weight, assuming that the portland cement weighed 94 lb/cu ft, hydrated lime 40 lb/cu ft, and that 1 cu. ft. of loose, damp sand contained 80 lb of dry sand. (Brixment masonry cement was assumed to weigh 65 lb/cu ft.)
[b] Used in backings for stucco-faced walls.
[c] Putty was made from Standard Lime and Stone Co.'s "Washington" brand, powdered quicklime. (See table 5, BMS82.)
[d] Used in backing, for gunite-faced walls.
[e] Used to caulk the joints between "Knap" units.
[f] Used to point the joints between "Knap" units.

Table 2.—*Sand sieve analyses*

Identification of sand[a]	Weight passing U. S. Standard Sieve number					
	4	8	16	30	50	100
	%	%	%	%	%	%
Sand *A*	100	100	93	70	19	2
Sand *B*	100	98	84	55	20	2

[a] Sand *A* was used in the stucco-faced and "Knap concrete unit" walls. Sand *B* was used in the gunite-faced walls.

(e) *Stucco*

The letter designations, proportions, and physical properties of the stuccos are given in table 3. Proportioning was by weight, and the amount of water added to the mixtures was

adjusted to the satisfaction of the mason. The stuccos were mixed in the same mixer used for the mortars.

(*f*) *Gunite*

Damp sand, containing about 6.6 percent of moisture, and portland cement were proportioned by weight and placed in a stock pile for use in the cement gun. The weight proportions were 1 part of cement to about 4.25 parts of dry sand. The volume proportions were 1 part of cement to 5 parts of loose damp sand.

(*g*) *Metal Reinforcement for Gunite-Faced Walls*

The reinforcement used in the gunite facings of two walls was galvanized, welded wire fabric, 2- by 2-in. mesh. The horizontal wires were No. 14 and the vertical ones No. 15 gage. Short lengths of No. 18 gage wire were used to anchor the mesh to the backings.

3. Construction of the Walls

(*a*) *Designation*

The walls were numbered consecutively as built, and all except those built of the "Knap" units, B241 and B242, are also identified by the following additional letter designation: The first two letters identify the kind of stucco or gunite facing. The next letter (in italics) represents the kind of unit in the backing, and the final letter designates the time interval between application of the scratch and finish coats of stucco. For example, wall B69, built with a backing of brick *c* and a facing of SA stucco which was applied in two coats, "N" (1 day) apart, is designated as wall B69–SAcN.

(*b*) *Stucco-Faced Walls*

The 8-in. walls for the stucco facings were built with mortar 2 and either brick *c*, tile *j* laid on end, or the concrete blocks *m* or *n*. The interior portions of the vertical joints were not filled with mortar, and the backings were of a highly permeable type of construction, workmanship B, described in BMS82. All of the units were dry when laid. The backings were aged and dried indoors for at least 2 weeks before the facings were applied.

The stucco-faced walls, listed in table 4, differed among themselves in the kind of backing unit, the moisture content of the backing when the stucco was applied, the kind of stucco facing, the length of time between the application of the scratch and finish coats, or in the curing.

The stucco was applied with a plastering trowel and rodded upward with a wooden straightedge worked against vertical wooden screeds at each end of the wall. Additional stucco was applied after each rodding until a thickness of about one-half in. was obtained. When the scratch coat had stiffened sufficiently, it was floated with a wooden float and then scratched. The scoring, $\frac{1}{16}$ in. deep, was in long diagonal lines intersecting at intervals of 2 in. The time required to apply and rod the scratch coat or to float and score it was about 10 min. The interval between rodding and scoring, usually 2 or 3 hr, depended upon the "suction" of the backing, which affected the rate of stiffening of the stucco. The scratch coat applied to the dry brick backing of wall B70 was scored 10 min after rodding, whereas the stucco repeatedly dropped from the lower third of the saturated brick backing of wall B71. It required 3 hr of labor and the addition of a dry stucco mixture before the latter wall could be rodded, and a second 3-hr period elapsed before the scratch coat was scored.

The finish coat was usually applied 1 day after application of the scratch coat (footnote a, table 4). The scratch coats were well dampened before the application of the stucco for the finish coats. The time interval between screeding and floating of the finish coat was usually about 2 hr, the shortest interval being 24 min for wall B70. The surface texture designated as rough was obtained by use of a wooden float, a smooth texture by the use of a plastering trowel.

The walls were cured, as described in table 4. Normal curing consisted in storing the walls at room temperature and humidity and in wetting them daily for 1 week after the application of each coat of stucco. The other curing was by storage in rooms with controlled temperature.

TABLE 3.—*Proportions and physical properties of stucco mixtures*

Designation symbol	Proportions of portland cement, hydrated lime, dry sand, and admixtures, by weight [a]	Average water content by weight of dry materials	Average initial flow [b]	Average 28-day compressive strength [c]	
				Air-cured	Water-cured
		Percent	*Percent*	*lb/in.²*	*lb/in.²*
SA	1:0.1:3.0:0	20.5	135	1,380	2,660
SB	1:0.2:3.6:0	20.9	112	1,620	1,820
SC	1:0.4:4.9:0	21.6	94	690	890
SD	1:0.1:3.6:0.3 [d]	19.8	132	1,120	1,820
SE	1:0.1:3.6:0.03 [e]	29.6	90	540	640
SF	1:0.1:3.0:0 [f]	20.5	135	1,380	2,660

[a] The portland cement met the physical requirements of Federal Specification SS–C–191a. The lime hydrate was contained in a putty made from the Standard Lime and Stone Co.'s "Washington" brand, powdered quicklime.

[b] Consistency was determined according to Federal Specification SS–C158.

[c] Determined from 2-in. cubes, cured in air with the walls or in water at 70° F.

[d] Pulverized limestone.

[e] Asbestos fibre.

[f] The finish coat contained dry pebbles, dashed against the troweled surface.

(c) *Gunite-Faced Walls*

The gunite-faced walls are listed in table 5. The backings for the walls were built with mortar 3, and they were of a similar construction to those used for stucco-faced walls. The structural clay tile *v* were laid on end in the first two courses and on the side in the upper two courses. All joints in the brick backings and the vertical joints in the tile backings were raked to a depth of one-half in. to provide a key for the gunite. The reinforcement in walls G2 and G4 was rigidly fixed at a distance of one-fourth in. from the face of the backings. The dry gunite mixture, previously described, was moved from the stock pile to the charging hopper of the cement gun, from which it was carried by compressed air, through a hose, to the mixing nozzle. Water was added at the nozzle as the mixture was shot against the face of the wall. When the gunite had been applied to a depth of about one-half in. the surface was raked with the edge of a plastering trowel. Immediately the second coat of gunite was applied to a thickness of about one-eighth in. greater than the final thickness, and the excess was rodded with a wooden straightedge worked against vertical grounds. The walls were cured at room temperature and humidity ("normal" curing given stucco-faced walls).

TABLE 4.—*Description and curing of stucco-faced walls*

Wall	Designation [a]	Moisture content of backing [b]	Curing of facings			Texture of finish coat [d]
			Kind of curing [c]	Condition of air in curing room		
				Average temperature during curing	Average relative humidity during curing	
				° *F*	*Percent*	
B94	SA*j*N	Dry	Controlled	34	[e] 68	Rough.
B95	SA*j*N	do	do	69	[e] 53	Do.
B70	SA*c*N	do	do	97	[e] 31	Do.
B69	SA*c*N	Medium dry	do	37	[f] 78	Do.
B72	SA*c*N	Medium wet	do	70	[f] 76	Do.
B71	SA*c*N	Saturated	do	93	[f] 60	Do.
B73	SA*j*M	Dry	Normal	64	54	Do.
B74	SA*j*N	do	do	65	52	Do.
B76	SA*j*O	do	do	60	38	Do.
B77	SA*j*P	do	do	61	42	Do.
B78	SA*m*N	Normal	do	60	42	Do.
B249	SA*n*N	do	do	80	60	Smooth.
B273	SA*n*N	do	do	80	60	Rough.
B79	SB*m*N	do	do	60	38	Do.
B80	SC*m*N	do	do	61	36	Do.
B250	SC*n*N	do	do	80	60	Smooth.
B274	SC*n*N	do	do	80	60	Rough.
B81	SD*m*N	do	do	59	33	Do.
B82	SE*m*N	do	do	58	31	Do.
B83	SF*m*N	do	do	58	31	(g)

[a] The first two letters denote the kind of stucco used in the facing, the letter in italic designates the kind of masonry unit used in the backing, and the final letter denotes the time interval elapsing between the completion of the scratch coat and the application of the finish coat, as follows: M=3.4 hr; N=1 day; O=1 week; P=2 weeks.

[b] The backings of all the walls were dried in warm air for several weeks after their construction. Backings of normal moisture content were wetted to the satisfaction of the mason before the scratch coat was applied. Walls B69, B72, and the saturated wall B71 contained about 47, 94, and 135 lb of water, respectively, when the scratch coat was applied. The backings in walls marked "dry" were not wetted.

[c] The walls were cured for 1 week after the application of each coat of stucco. Walls given "controlled" curing were stored in rooms in which the temperature was controlled. Walls given normal curing were stored indoors and wetted daily for 1 week.

[d] A rough surface was obtained with a wooden float; a smooth surface with a plastering trowel.

[e] The scratch coat was wetted only before the finish coat was applied. The finish coat was not wetted.

[f] Wetted daily, and covered with wet burlap draped a few inches from the stucco facings.

[g] Wood floated and then garnished with 15 lb of Potomac River gravel, thrown against and embedded in the plastic surface. The gravel passed a ¾-in. screen; minimum size was ⅜ in.

TABLE 5.—*Gunite-faced walls*

Wall	Designation [a]	Kind of backing	Reinforcement in gunite	Nominal thickness of gunite facing
				in.
G1	GP*y*	Brick *y*	None	0.75
G2	GR*y*	do	Steel fabric	1.00
G3	GP*v*	Tile *v*	None	0.75
G4	GR*v*	do	Steel fabric	1.00

[a] The first 2 letters denote the kind of gunite facing (either GP for plain, or GR for reinforced gunite), the last letter denotes the kind of unit used in the backing.

(d) *"Knap Concrete-Unit" Walls*

The "Knap concrete-unit" walls were of a construction similar to those built for the structural tests described in BMS40. Holes in vertical ribs of the units matched those drilled in vertical wooden splines, and steel spikes were used as dowels to connect the splines and panels. After assembling the units in the wall, the joints were caulked with mortar (mortar 4, table 1) and raked to a depth of one-half in. Two days later the joints were pointed with mortar 5.

The exposed face of wall B241 contained four half-length units, 21½ in. high, forming a vertical- and a horizontal-joint intersection at the center of the wall. The back contained a standard unit of full length, 39½ in. long, which rested upon a half-height unit of the same length and was surmounted by another. In wall B242 the assembly was reversed. The exposed faces of both walls were given two coats of "Bondex" paint applied after the first permeability tests had been completed.

III. TESTING OF THE WALLS

1. Water-Permeability Test

The water-permeability test simulated heavy wind-driven rain, but was of greater duration than most natural wind and rain storms to which building walls are subjected. Ordinarily, information of a practical value on the permeability of the specimens may be obtained during 1-day exposures. However, for determination of the relative permeability of the walls, or of possible slight changes in permeability resulting from weathering, the tests were sometimes continued for a maximum of 5 days. All of the walls were given a preliminary conditioning exposure of 2 days' duration and then dried to nearly constant weight before being tested for record.

(a) *Apparatus and Method*

The testing apparatus is illustrated and described in BMS82. The walls formed one side of a pressure chamber containing air maintained at a pressure of 10 lb/ft^2 above that of the atmosphere. The face of the wall inside the chamber, referred to as the exposed face, was covered with a film of water flowing at the rate of 40 gal/hr. The relative humidity of the air in the testing room was usually above 80 percent, and the temperature of the water applied to the wall was maintained above the dew point. The backs of the walls were whitewashed so that any discoloration produced by the penetration of moisture could be easily detected.

(b) *Observations*

Observations of the specimens were continual for the first several hours of each test, after which they were made at increasingly longer intervals.

The following observations were made:

(1) Time required for the appearance of moisture (dampness) on the backs of the walls, above the flashings.

(2) Time required for the appearance of visible water on the backs of the walls, above the flashings.

(3) Time required for leakage to flow from the flashings.

(4) Maximum rate of leakage, if any.

(5) Extent of damp area on the backs of the walls, including that produced by the capillary rise of moisture from water on the flashings.

The time of failure, when not exactly determined, was assumed to be the middle of the interval between two inspections, and the uncertainty of the observation was assumed as plus or minus one-third of the interval between the two inspections.

(c) *Rating of Performance*

The arbitrary ratings of wall performance are based on the assumption that visible water, extensive dampness on the back, or leakage through the base of a wall, would damage plaster where applied directly to the wall, or would injure the interior trim or furnishings of a building. Since the exposure given the test walls was controlled to prevent condensation of moisture on the backs, and since failure occurred only through the penetration of moisture from the exposed face of the specimens, no conclusions can be drawn from the tests regarding the effects of condensation in building walls similar to the test specimens.

Wall performance ratings:

Excellent (*E*).—No water visible on back of the wall (above the flashings) at the end of 1 day. Not more than 25 percent of the wall area damp at the end of 5 days. No leaks [4] through the wall in 5 days.

Good (*G*).—No water visible on back of the wall at the end of 1 day. Less than 50 percent of the wall area damp at the end of 1 day. No leaks [4] through the wall at the end of 1 day.

Fair (*F*).—Water visible on back of wall in more than 3 or less than 24 hr. Rate of leakage through the wall less than 1 liter per hour at the end of 1 day.

Poor (*P*).—Water visible on the back in 3 hr or less. Rate of leakage less than 5 liters per hour at the end of 1 day.

Very Poor (*VP*).—Rate of leakage through the wall equal to or greater than 5 liters per hour at the end of 1 day.

2. Outdoor Exposure

The walls were exposed to the weather at Washington, D. C., for periods ranging from 16 to 49 months, within the interval February 1938 to December 1941, inclusive, and they were tested for permeability both before and after being exposed.

The monthly maximum and minimum air temperatures and the monthly mean of daily maximum and daily minimum air temperatures are shown in figure 2, which also shows the number of thawing cycles per month. Data obtained from the Weather Bureau indicated that the air temperature did not rise to above freezing more than once in any one day. The monthly precipitation for the period January 1938 to December 1941, inclusive, is given in table 6.

[4] Leaks are defined as follows: A leak is a flow of water from one or both flashings, the total rate of flow being equal to or greater than 0.05 liter per hour.

Table 6.—*Monthly precipitation*

Month	1938	1939	1940	1941	Normal
	in.	*in.*	*in.*	*in.*	*in.*
January	2.6	3.4	2.1	3.0	3.6
February	2.4	5.7	2.8	0.9	3.3
March	2.2	2.9	3.4	2.6	3.8
April	1.7	3.8	6.2	2.7	3.3
May	3.5	0.4	3.1	1.6	3.7
June	2.3	4.6	0.9	4.4	4.1
July	5.1	2.0	5.7	5.7	4.7
August	4.6	3.2	5.0	1.9	4.0
September	4.3	6.9	1.3	0.5	3.2
October	1.2	4.1	2.1	1.1	2.8
November	2.6	1.4	5.3	0.8	2.4
December	2.7	2.2	2.3	3.9	3.3
Total	35.2	40.6	40.2	29.1	42.2

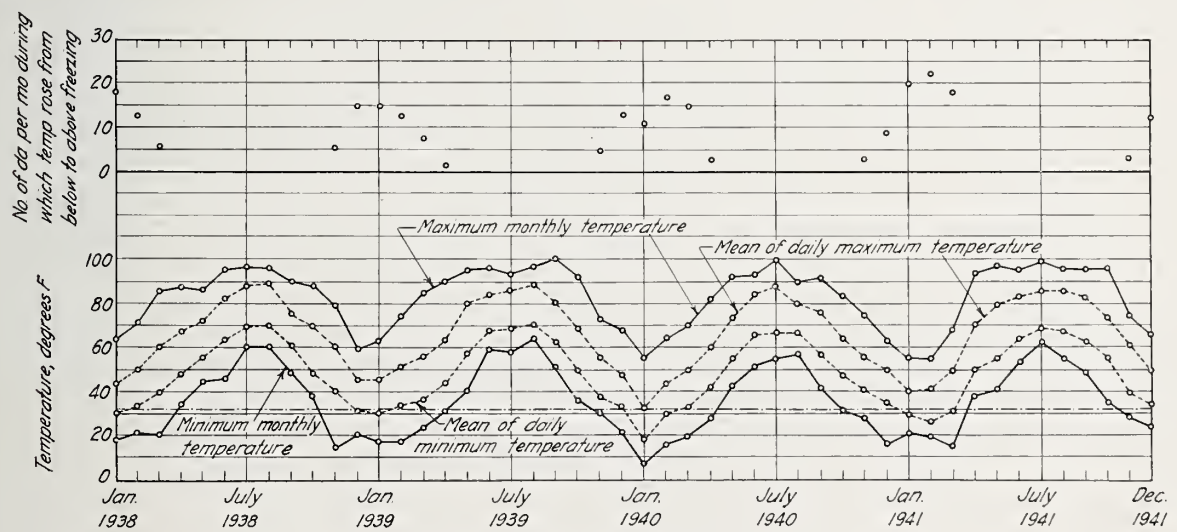

Figure 2.—*Temperature record.*

IV. RESULTS OF THE TESTS

1. Permeability of the Stucco-faced Walls

(a) *Effect of Temperature and Humidity During the Curing of Stucco Facings*

The air temperature during the curing of the walls listed in group I of table 7 was maintained at 35°, 70°, or 95° F (table 4), but the relative humidity was not controlled. Consequently in order to determine the effects of moisture conditions during curing, some of the specimens were protected from drying by daily wetting and by draping with wet burlap, and others were neither wetted nor protected. The high absorptive capacity of the brick in wall B70 accelerated the drying of the stucco, whereas the water in the brick backings of walls B71 and B72 tended to keep the stucco damp.

Since all of the walls in group I, table 7, were rated "excellent" in the permeability tests made before the walls were stored outdoors, it is evident that the range in the conditions during early curing had no significant effect on permeability. It should be noted, however, that the drying to which the test walls were subjected may not have been so rapid or so nearly complete as that to which exterior stucco-faced walls built of similar materials and exposed to the sun and wind may be subjected.

Table 7.—*Water permeability of walls*

Wall	Designation [a]	Date placed outdoors [b]	Duration of outdoor exposure	Time to failure as evidenced by [c]			Maximum rate of leakage per hour	Area damp in 1 day	Rating
				Damp	Visible water	Leak			
1	2	3	4	5	6	7	8	9	10
Stucco-faced walls, group I: Effect of curing temperature									
			Months	*Hours*	*Hours*	*Hours*	*Liters*	*Percent*	
B94	SAjN		0				0	0	*E*
		Nov. 1938	31				0	0	*E*
B95	SAjN		0				0	0	*E*
		Nov. 1938	31				0	0	*E*
B70	SAcN		0				0	0	*E*
		Aug. 1938	32				0	0	*E*
B69	SAcN		0				0	0	*E*
		Aug. 1938	32	10±2	53±1		0	5	*G*
B72	SAcN		0				0	0	*E*
		Aug. 1938	31				0	0	*E*
B71	SAcN		0				0	0	*E*
		Aug. 1938	31	17±4			0	3	*E*
Stucco-faced walls, group II: Effect of time interval between application of scratch and finish coats									
			Months	*Hours*	*Hours*	*Hours*	*Liters*	*Percent*	
B73	SAjM		0				0	0	*E*
		Aug. 1938	31				0	0	*E*
B74	SAjN		0				0	0	*E*
		Aug. 1938	31				0	0	*E*
B76	SAjO		0				0	0	*E*
		Sept. 1938	32				0	0	*E*
B77	SAjP		0				0	0	*E*
		Sept. 1938	32				0	0	*E*

[a] The first two letters denote the kind of stucco or gunite used in the facing. The third letter denotes the kind of masonry units used in the backing. For stucco-faced walls, the final letter gives the length of time interval between application of the scratch and finish coats, see note "a" of table 4.

[b] The walls were tested for permeability before being placed outdoors and data from these tests are given in the first line for each respective wall in the table. Data from the tests made after outdoor exposure are given in the second line unless otherwise noted.

[c] The uncertainty of the observation is given if it exceeds 10 percent of the total elapsed time. A dash indicates no failure of the wall.

TABLE 7.—*Water permeability of walls*—Continued

Wall	Designation [a]	Date placed outdoors	Duration of outdoor exposure	Time to failure as evidenced by [c]			Maximum rate of leakage per hour	Area damp in 1 day	Rating
				Damp	Visible water	Leak			
1	2	3	4	5	6	7	8	9	10
					Stucco-faced walls, group III: Effect of kind of stucco facing				
			Months	*Hours*	*Hours*	*Hours*	*Liters*	*Percent*	
B78	SA*m*N		0				0	0	*E*
		Sept. 1938	31				0	0	*E*
B249	SA*n*N		0				0	0	*E*
		Jan. 1940	16				0	0	*E*
B273	SA*n*N		0				0	0	*E*
		Dec. 1939	18				0	0	*E*
B79	SB*m*N		0				0	0	*E*
		Sept. 1938	31				0	0	*E*
B80	SC*m*N		0				0	0	*E*
		Sept. 1938	31				0	0	*E*
B250	SC*n*N		0				0	0	*E*
		Jan. 1940	17				0	0	*E*
B274	SC*n*N		0				0	0	*E*
		Dec. 1939	18				0	0	*E*
B81	SD*m*N		0				0	0	*E*
		Oct. 1938	31				0	0	*E*
B82	SE*m*N		0				0	0	*E*
		Oct. 1938	30				0	0	*E*
B83	SF*m*N		0				0	0	*E*
		Oct. 1938	31				0	0	*E*
					Gunite-faced walls				
G1	GP*y*		0				0	0	*E*
		Destroyed [d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
G2	GR*y*		0				0	0	*E*
		Feb. 1938	49				0	0	*E*
G3	GP*v*		0				0	0	*E*
		Feb. 1938	46				0	0	*E*
G4	GR*v*		0				0	0	*E*
		Feb. 1938	46				0	0	*E*
					"Knap concrete-unit" walls				
B241			0	0.7	39±6		0	3	*G*
		[e]	0				0	0	*E*
		Aug. 1939	24	.2	.4	0.4	17	35	*VP*
B242			0	.7	2.2	.7	1.1	10	*P*
		[e]	0				0	0	*E*
		Aug. 1939	24	.1	.1	.2	3.8	10	*P*

[d] Accidentally destroyed while stored outdoors.
[e] Painted with "Bondex" and again tested before being stored outdoors.

(b) *Effect of Time Interval Between Application of the Scratch and Finish Coats*

The intervals between the application of the scratch and the finish coats of SA stucco to the tile backings of the walls listed in group II, table 7, were 3.4 hr, 1 day, 1 week, and 2 weeks, respectively, for walls B73, B74, B76, and B77. The scratch coats on walls B76 and B77 were wetted daily until the finish coat was applied.

The performances of all of the walls in the permeability tests were rated "excellent," indicating that the differences in the time intervals between application of the scratch and the finish coats had no significant effect. However, a more complete drying of the scratch coats, such as may occur in exterior walls exposed for many days without wetting, might have affected the permeability of test walls B76 and B77.

(c) *Effect of Kind of Stucco Facing and of Kind of Backing Unit*

The walls listed in group III, table 7, differed principally in the relative proportion of hydrated lime and cement in the facings or in the use of admixtures such as powdered limestone or asbestos fiber. All of these walls were rated "excellent," and there were no significant differences noted in their performances.

Similarly, facings of SA stucco were equally effective when applied to backing built of any of the four kinds of masonry units, and facings of SC stucco were likewise equally effective when applied to backing of either stone or cinder concrete block.

Tests described in BMS82, and other tests,[5] were made on masonry walls built of like materials and in a like manner to the specimens used as backings for the stucco facings. The tests showed that such walls were highly permeable, had a high rate of leakage, and were rated "very poor." The backings were not tested before the facings were applied, but if they had been it is highly probable that they would likewise have been rated "very poor." After completion, all of the stucco-faced walls were exceptionally resistant to water penetration and were rated "excellent." It is evident that none of the variables in the kind of facings or in their method of application, in the kind of backings or in their moisture content, or in curing conditions given the facings had an important effect on permeability of the stucco-faced walls.

[5] Unpublished data on walls treated with cement-water paints and other waterproofings.

2. Permeability of Gunite-Faced and "Knap Concrete-Unit" Walls

(a) *Gunite-Faced Walls*

The four gunite-faced walls were highly resistant to water penetration and were rated "excellent" regardless of the kind of backing unit or type of facing (table 7).

(b) *"Knap Concrete-Unit" Walls*

Before being painted with "Bondex," wall B241, containing a vertical joint in the facing, was rated "good" and wall B242 was rated "poor" (table 7). Moisture first appeared at or below the joints in the backings, and particularly at the bases of the wall above the flashings. After they were painted, both walls were rated "excellent," indicating that the treatment was effective.

3. Effects of Outdoor Exposure on Structural Soundness

(a) *Stucco-Faced Walls*

When the stucco-faced walls were examined after outdoor storage, the facings were found to be more or less cracked or crazed. Most of them appeared to be warped slightly concave, and cracks were observed in the bed joints of some of the hollow-unit backings. These cracks extended through the end pargings at the elevation of the bed joints, but did not penetrate the stucco facings. Concavity in the facings appeared to be incidental and was not significantly affected by the kind of unit in the backings or by the kind of stucco facing. As no observations of the extent of crazing or warpage were made on the facings before the walls were placed outdoors, it is not known how much of their development resulted from weathering.

The walls were dry when the width of the cracks was measured with a 20-power Brinell microscope. Many cracks, particularly those

running horizontally, appeared to be filled or partly filled with material deposited in them. The maximum crack width, given in table 8, is the average width of two of the largest cracks located within the area exposed to the permeability test. The wider cracks were found in facings applied to structural clay tile, and the finer in walls backed with the brick *c* or with cinder concrete block *n*. One crack, in the top of wall B69–SA*c*N (fig. 3), may have been caused by frost in the brick backing. Although the units appeared to be in good condition, damage due to the freezing of water in the upper portions of walls built of the brick *c* has been observed, and is described in BMS76. There was no spalling nor loose stucco on any of the walls.

TABLE 8.—*Width of cracks in the stucco facings, after storage outdoors.*

Wall	Designation	Maximum width of cracks
		In.
B94	SAjN	0.007
B95	SAjN	.008
B70	SA*c*N	[a]
B69	SA*c*N	[b] .012
B72	SA*c*N	.003
B71	SA*c*N	.005
B73	SAjM	.010
B74	SAjN	.008
B76	SAjO	.009
B77	SAjP	.011
B78	SA*m*N	.004
B249	SA*n*N	.003
B273	SA*n*N	.003
B79	SB*m*N	.005
B80	SC*m*N	.008
B250	SC*n*N	.004
B274	SC*n*N	.005
B81	SD*m*N	[a]
B82	SE*m*N	.008

[a] No cracks noted in the inner areas of the stucco facings, when dry.
[b] No cracks noted except at top of the wall, see figure 3. Width of crack about 0.04 in. when observed in spring of 1942.

After the walls had been tested for permeability, they were placed outdoors until April 1942, when the width of the cracks in some of them was again measured. Little or no change was noted in the width of cracks in any except wall B69, and the maximum width of cracks in the top of this wall had increased from about 0.012 in. to 0.04 in.; the large increase in crack width indicates a structural failure not common to the other walls.

The extent of crazing in some of the stucco facings is indicated in figures 3 to 10, inclusive. The walls had been wetted and then photographed while partly dry so that moisture left in the cracks accentuated them. In general, there was less crazing noted in the facings of SA stucco applied to backings of brick *c* or of concrete block *m* and *n* than for the tile *j* (figs. 4, 5, and 6). The relative proportions of hydrated lime and cement in facings applied to the block *m* had little effect, although a slight increase in the size of cracks was noted with increase in the proportion of lime (table 8 and figs. 6, 7, and 8). The stucco facing containing asbestos fiber was cracked, or crazed, to a greater extent than was that containing pulverized limestone (table 8 and figs. 9 and 10). Cracks in stucco facings applied to hollow-unit backings were transverse to the joints in the backings and usually interseeted each other near the centers of the units, as in figures 5 and 7.

(b) *Gunite-Faced Walls*

The gunite-faced walls were accidentally overturned while stored outdoors but, when righted, only one of the four was found to be damaged. No crazing was noted in the dry gunite facings resulting from 4 years of weathering exposure, and these walls appeared to have a higher resistance than did the stucco-faced walls.

(c) *"Knap Concrete-Unit" Walls*

The motor joints in the facings of the "Knap concrete-unit" walls were found to be cracked when examined after 2 years of outdoor storage. The largest of these cracks was about 0.008 in. wide. The walls were less rigid than those faced with gunite or stucco, and it is probable that the cracks in the joints were opened or enlarged when the walls were transported to and from the storage area.

4. Effects of Weathering Exposure on Permeability

All of the stucco- and gunite-faced walls, except B69, were rated "excellent" after exposure outdoors, and the weathering had little or no significant effect. Water entered a crack in the top of wall B69 (fig. 3) and penetrated the wall in about 10 hr. The back of the wall was 5-percent damp after 1 day, but was 40-percent damp in 3 days so that it was rated "good" instead of "excellent."

FIGURE 3.—*Wall B69 SACN after weathering.*

The wall was wetted daily and cured in damp air at a temperature of 37° F for 1 week. The jagged lines at top of the wall indicate the extent of cracking observed on the dry wall. The width of cracks measured at *b*, *d*, and *i* (indicated by transverse lines) was about 0.012 in.

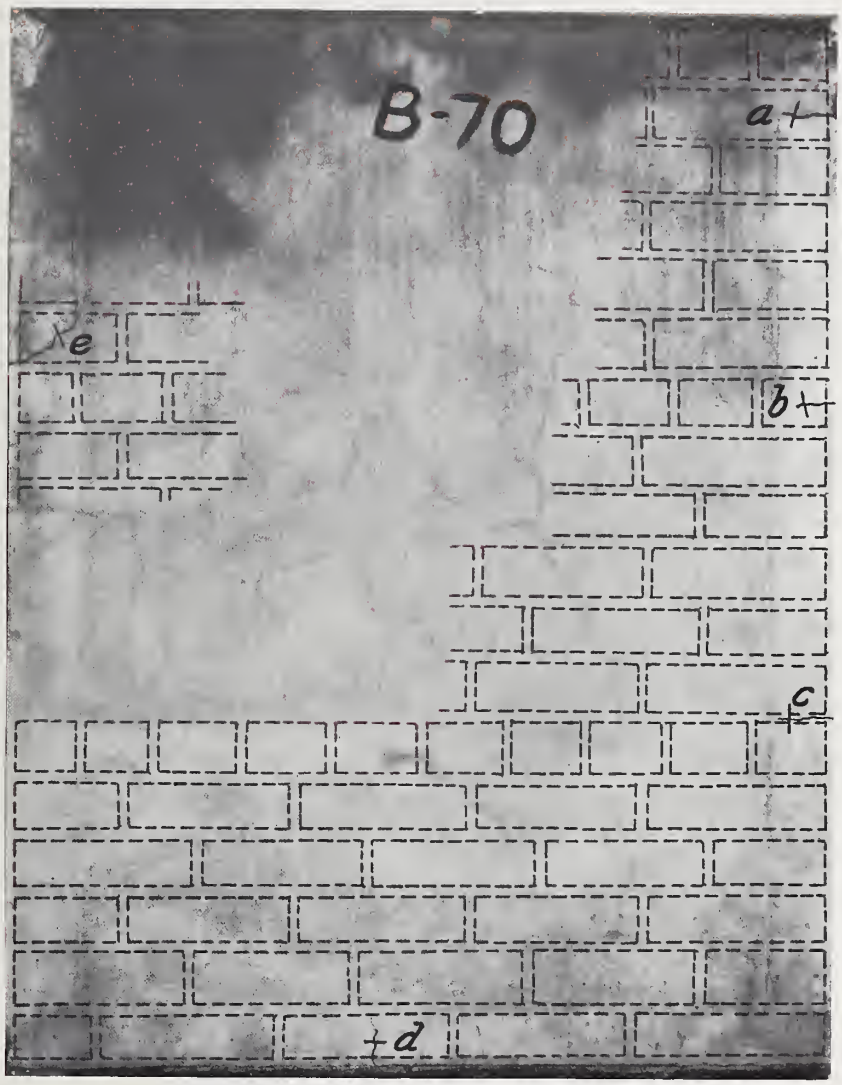

FIGURE 4.—*Wall B70 SACN after weathering.*

The wall was cured in dry air, without wetting, at a temperature of 97° F for 1 week. The brick backing is indicated in dashed lines. The lines at *a*, *b*, *c*, *d*, and *e* indicate the extent of cracking observed on the dry wall. The width of these cracks was about 0.003 in.

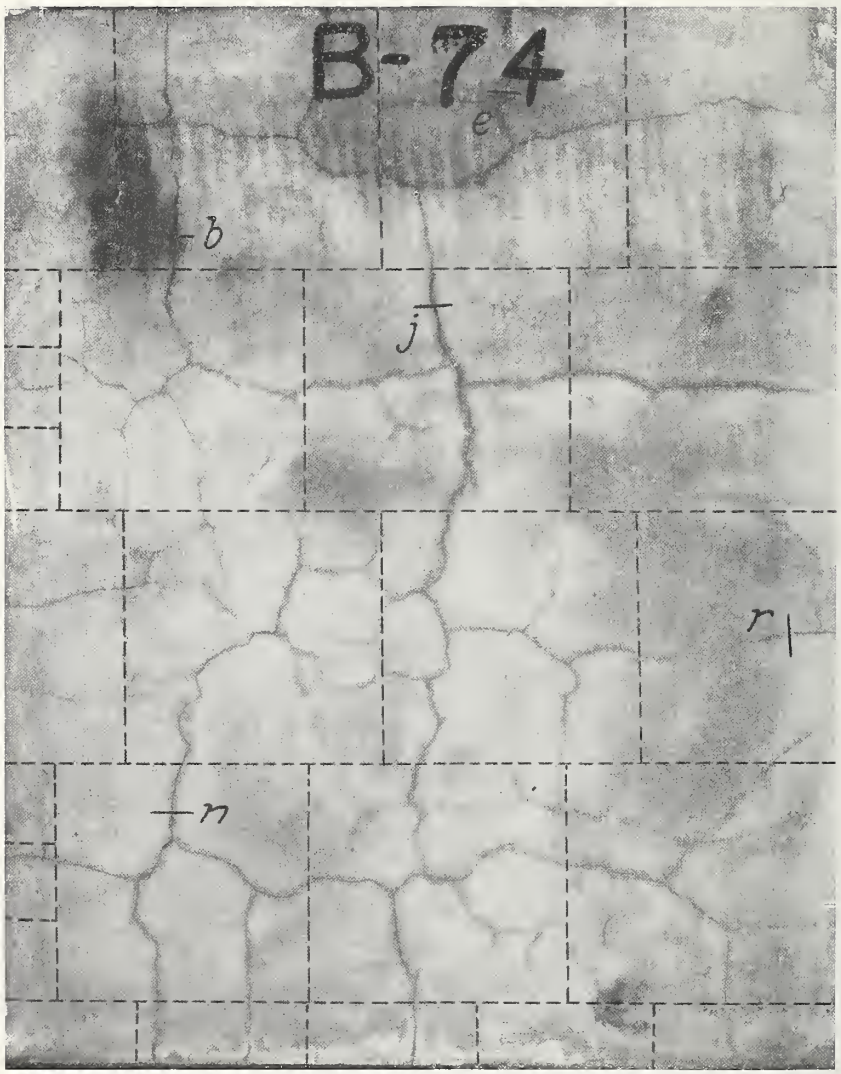

FIGURE 5.—*Wall B74 SAjN after weathering.*

The structural clay tile backing is indicated in dashed lines. The width of cracks at *b*, *e*, *j*, *n*, and *r* (indicated by transverse lines) was about 0.008 in. Extensive crazing was noted on the dry wall.

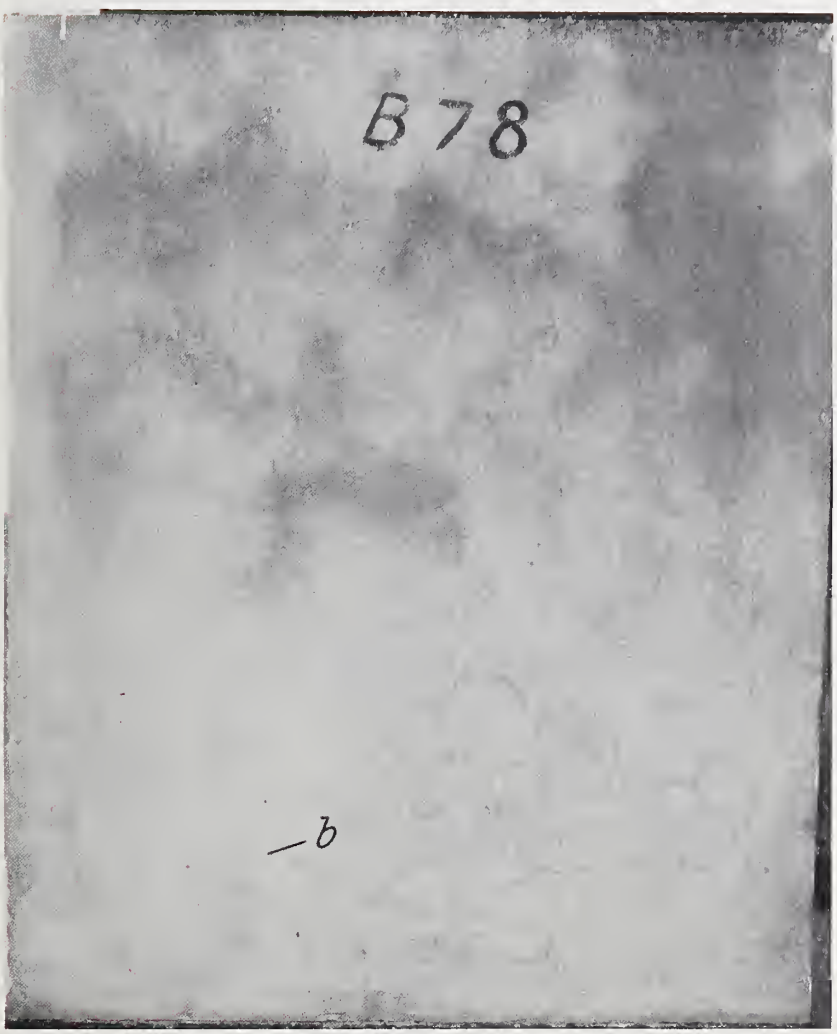

FIGURE 6.—*Wall B78 SAMN after weathering.*

The width of crack at *b* (indicated by transverse line) was 0.004 in. Only four short (vertical) cracks were observed on the dry wall, all in the lower third of the facing.

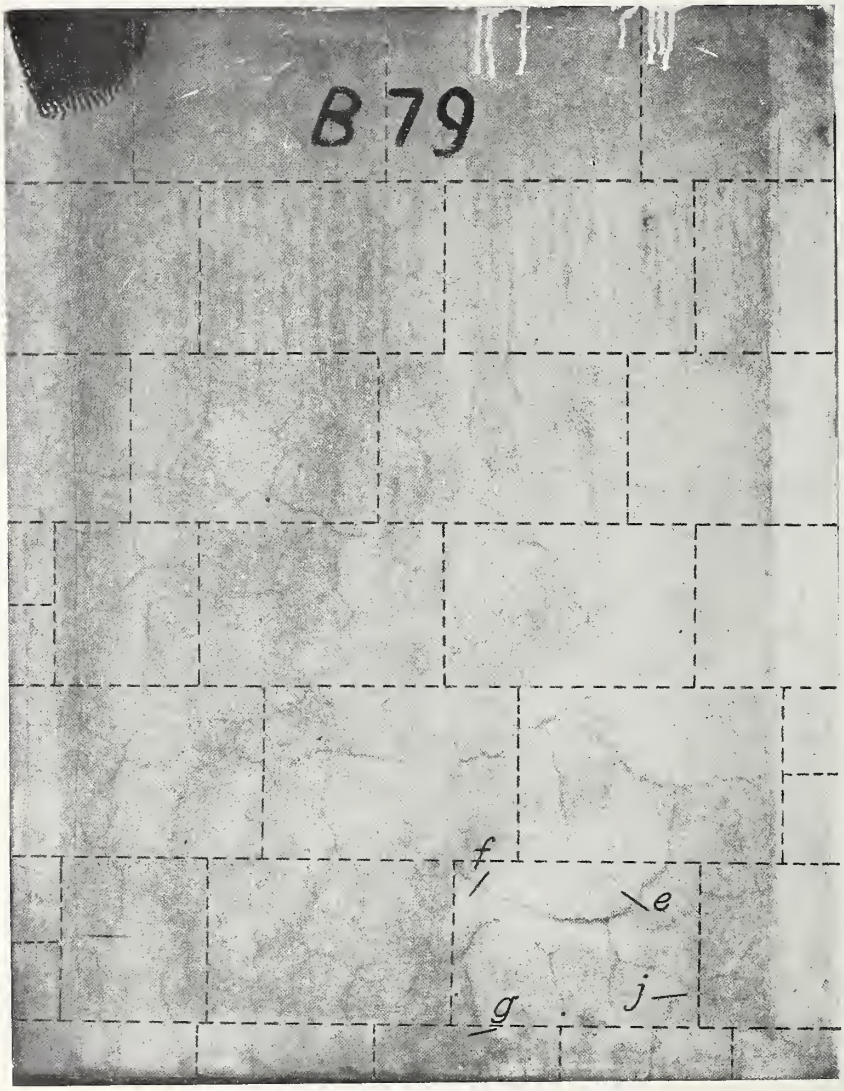

FIGURE 7.—*Wall 79 SBmN after weathering.*

The stone concrete block backing is indicated in dashed lines. The width of crack at *e* (indicated by transverse lines) was about 0.007 in. Extensive crazing was noted on the dry wall.

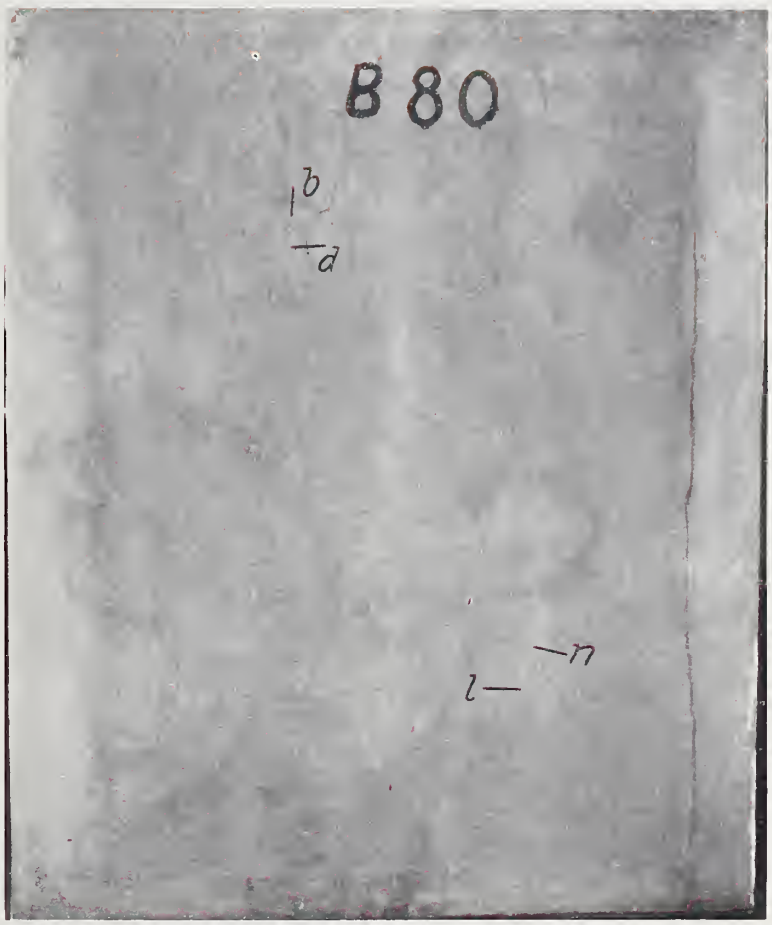

FIGURE 8.—*Wall B80 SCmN after weathering.*

Extensive crazing was observed in the dry wall. The width of cracks at *b*, *d*, *l*, and *n* (indicated by transverse lines) was about 0.008 in.

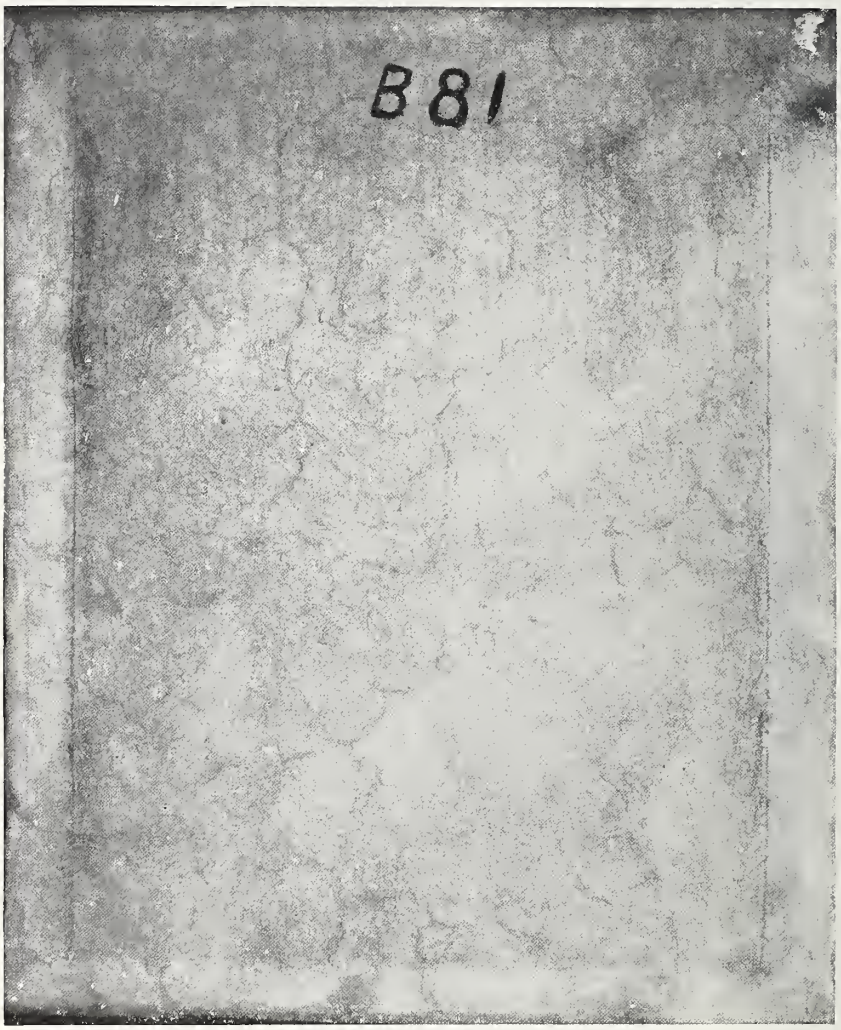

FIGURE 9.—*Wall B81 SDmN after weathering.*

No cracks were noted on the dry wall.

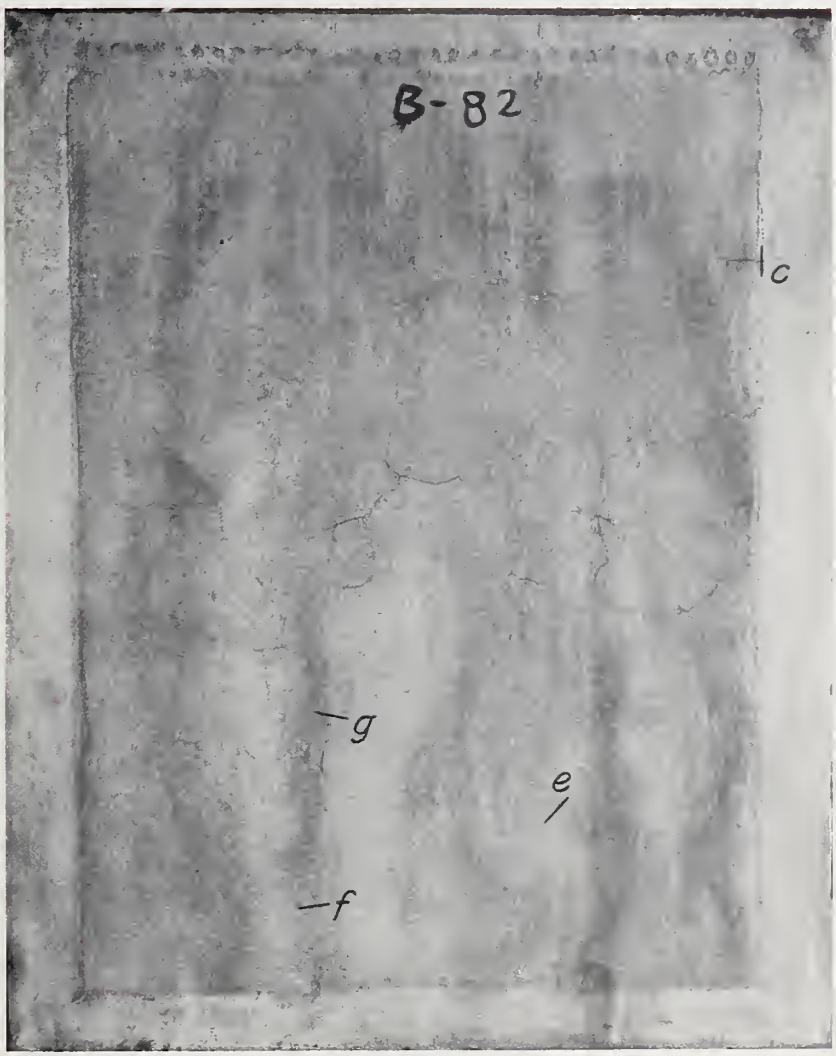

FIGURE 10.— *Wall B82 SEmN after weathering.*

The width of cracks at *g*, *e*, and *f* (indicated by transverse lines) was about 0.008 in. Extensive crazing was noted on the dry wall.

Tests of eight stueco-faeed walls reported in BMS76 indieated a signifieant but not a serious inerease in permeability after a period of outdoor exposure. Before exposure, five of eight walls were rated "exeellent" and three "good." After weathering exposures lasting 2 or 3 years, one wall was rated "exeellent," five "good," one "fair," and one "poor."

The two painted "Knap conerete-unit" walls whieh were rated "exeellent" in tests prior to 2 years of outdoor storage, when tested after weathering, were rated "poor" and "very poor" (table 7). Wall B241, eontaining a vertieal joint in the faeing, leaked exeessively, although it is probable that the joints in both walls were damaged during removal to and from the storage yard. Even so, repainting of the joints would have effectively sealed them so that the walls would again show a high resistanee to water penetration.

V. SUMMARY AND CONCLUSIONS

Twenty stueco-faced, four gunite-faeed, and two walls built of "Knap eonerete units" were tested for water permeability before and after exposure to the weather. The backings of the stucco-faeed walls varied in their moisture eontent and in the kinds of masonry unit; the faeings varied in the relative proportion of portland eement and hydrated lime, the time intervals between applieation of the sratch and finish coats, and in the curing. The gunite-faeed walls differed in the thickness and reinforeement of the faeings and in the kind of baekings. There were no eonstruction joints in the faeings of any of the speeimens, except in those built of "Knap eonerete units." Since the speeimens were small, and there were no adjaeent struetural members, the weathering exposure did not simulate all the eonditions whieh may produee struetural cracks in a large wall.

The following eonelusions were derived regarding the permeability and struetural soundness of the walls:

1. The stueeo- and gunite-faeed walls were very highly resistant to water penetration when first construeted.

2. Periods of outdoor exposure ranging from 17 to 32 months, at Washington, D. C., resulted in the formation of eraeks, or of erazing, in most of the stueeo facings, but there was no loose or spalled stueeo on any of the walls. There was little or no signifieant or important effect on the permeability of the walls produced by the weathering.

3. The gunite facings were not crazed by 4 years of weathering, nor was their permeability significantly affected.

4. Before they were painted with "Bondex," the "Knap eonerete-unit" walls were more permeable than either the stueeo-or gunite-faeed walls. Immediately after painting, their resistanees were eomparable to that of other walls.

Washington, September 5, 1942.

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[Continued from cover page II]

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